# Elastic interface device

The present invention is related to an elastic interface device.

Elastic interface devices, which are also often called flexures, are frequently used in high precision mechanisms to couple or join together at least two structural parts and to allow relatively small displacements or movements between said two structural parts with negligible virtual play. In kinematic part fixations such elastic interface devices are used to avoid over-determination in part connections and to create a thermo-mechanically stable fixation for high precision components.

Elastic interface devices enable high accuracy and a good deterministic behavior at relatively low cost. In order to meet optimized demands on for example thermal stability and reproducibility, elastic interface devices are preferably made or built into a monolithic structure. However, such elastic interface devices built into a monolithic structure are generally characterized by a lack of sufficient damping, thereby resulting in significant amplification at resonance conditions. For that, elastic interface devices built into a monolithic structure are less suitable for dynamic loads, because of the fact that vibrations, especially vibrations at resonance frequencies, will continue to exist or will even be enlarged instead of damped out. Without damping treatment, such elastic interface devices would fail in particular cases.

From prior art it is known to provide damping means, wherein the damping means are applied via additional dampers attached between the structural parts coupled or joined together by such an elastic interface device, wherein the additional dampers are connected in parallel to the elastic interface device between the structural parts. However, such additional dampers positioned in parallel to the elastic interface device between the structural parts disturb the accuracy and the deterministic behavior by the over-determination of the elastic interface device that is caused by the additional dampers in parallel.

US 6,325,351 B1 discloses a kinematic coupling for precision instruments comprising two legs, wherein said two legs are at a first end secured to a housing. At a second, opposite end the legs are joined together by means of a ball-cone joint. Each of the

legs includes a flexure member defining a slit, and in addition to that flexure member an additional damping means, wherein the damping means comprise a stiff structural element as part of the leg outside the flexure blade, provided with viscoelastic layers and constraining layers. The flexure member and the damping means are designed to be in parallel as independent means both individually and separately mounted into the legs.

It is an object of the present invention to provide an improved elastic interface device.

The present invention provides an elastic interface device for coupling or connecting at least two structural parts, wherein said elastic interface device allows preferably a relative displacement or movement between said at least two structural parts, and wherein at least one constrained-layer damping structure is incorporated or integrated into said elastic interface device. Preferably, the or each constrained layer damping structure is attached, especially fixedly attached, to said elastic interface device.

In accordance with a preferred embodiment of the present invention the or each constrained-layer damping structure is attached, preferably fixedly attached, to at least one flexible portion of said elastic interface device. For optimal damping, the or each constrained-layer damping structure has a stiffness in the same order of magnitude as or at least not negligible compared to the or each flexible portion of said elastic interface device to which the constrained-layer damping structure is attached.

Preferably, the or each constrained-layer damping structure comprises at least two layers, a first viscous or viscoelastic layer and a second constraining layer. The first viscous or viscoelastic layer is sandwiched between the flexible portion of said elastic interface device and said second constraining layer.

Fig. 1 shows an elastic interface device according to a first embodiment of the present invention;

Fig. 2 shows an elastic interface device according to a second embodiment of the present invention; and

Fig. 3 shows an elastic interface device according to a third embodiment of the present invention.

Fig. 1 shows a first embodiment of an elastic interface device 10, which is designed as a leaf spring. The elastic interface device 10 or leaf spring is formed into a monolithic structure 11, wherein the leaf spring separates the monolithic structure 11 in at least two structural parts, wherein said two structural parts are connected or coupled by said elastic interface device 10, namely by said leaf spring.

In Fig. 1, only one of said two structural parts is shown, namely the lower structural part 12. It should be noted that the entire arrangement of Fig. 1 is symmetrically designed with respect to an axis of symmetry running in parallel with the x-axis of the coordinate system shown in Fig. 1. In order to simplify the drawing of Fig. 1, the upper structural part, which is connected or coupled to the lower structural part 12 by the elastic interface device 10, namely by said leaf spring, is not shown.

The elastic interface device 10, namely the leaf spring, according to Fig. 1 comprises a stiffened middle portion 13 having the thickness T and two flexible end portions 14, Fig. 1 showing only one of these two flexible end portions 14, and the flexible end portion 14 shown connecting the entire leaf spring 10 to the lower structural part 12. The flexible end portion 14 is characterized by the thickness $t_1$ and by its length $l_1$. The deformations of the elastic interface device 10, namely of the leaf spring, are particularly concentrated in these flexible end portions 14.

According to the present invention, at least one constrained layer damping structure is incorporated or integrated into the elastic interface device 10, namely into the leaf spring, wherein the or each constrained-layer damping structure is attached, namely fixedly attached, to the flexible end portions 14 of said leaf spring 10. In the embodiment according to Fig. 1, the leaf spring is designed symmetrically with respect to an axis of symmetry running in parallel with the x-axis and in addition with respect to an axis of symmetry running in parallel with the z-axis. For this purpose, in the embodiment according to Fig. 1, two constrained layer damping structures 15 and 16 are assigned, namely attached to each flexible end portion 14 of the leaf spring 10.

Each of the two constrained-layer damping structures 15, 16 comprises two layers, namely a first viscous or viscoelastic layer 17 and a second constraining layer 18. It can be taken from Fig. 1, that the first viscous or viscoelastic layers 17 are sandwiched between the flexible end portion 14 of said leaf spring 10 and the second constraining layers 18. The viscous or viscoelastic layers 17 provide shear layers which are attached to the flexible end portion 14. The second constraining layers 18 are additional beams or plate-like

elements that are loaded indirectly via the viscous or viscoelastic damping layers 17. For optimal damping, the constrained-layer damping structures 15, 16 provide a stiffness in the same order of magnitude as or at least not negligible compared to the flexible end portions 14 of the elastic interface device 10.

As shown in Fig. 1, the first viscous or viscoelastic layer 17 is characterized by the thickness $t_v$ and the length $l_2$. The second constraining layer 18 is characterized by the thickness $t_2$ and the length $l_2$. The second constraining layers 18 provide additional, small leaf springs on both sides of the flexible end portion 14.

The entire arrangement according to Fig. 1 is built into a monolithic structure 11 by a wire EDM process. Slots or cavities are provided in said monolithic structure 11, whereby said cavities or slots are filled with a viscous or viscoelastic material to provide the first viscous or viscoelastic layers 17. The stiffened middle portion 13, the flexible end portion 14, the second constraining layers 18, and the structural part 12 are all made of the same material. The second constraining layers 18 have a direct connection to the lower structural part 12, but not to the elastic interface device 10, namely to the leaf spring 10. Alternatively, the second constraining layers 18 have a direct connection to the stiffened middle portion 13, but not to the structural part 12. For that, the constraining layers 18 are loaded indirectly via the viscous or viscoelastic damping layers 17. The constraining layers 18 are coupled or attached to the flexible end portions 14 of the leaf spring 10 interposing the viscous or viscoelastic layers 17 acting as shear layers.

The embodiment according to Fig. 1 is most advantageous to primary damp out vibrations in the axial degree of freedom along the z-axis or in the transversal degree of freedom along the y-axis, but is also able to damp other degrees of freedom, e.g. a lateral degree of freedom along the x-axis. The second constraining layers 18 of the constrained layer damping structures 15 und 16 of the embodiment of Fig. 1 act as additional small leaf springs, which are able to provide stiffness in the corresponding directions.

Fig. 2 shows a second embodiment of an elastic interface device 19, which is most advantageous to primary damp out vibrations in the torsional degree of freedom, which corresponds to a rotation around the z-axis, or in the bending degree of freedom, which corresponds to a rotation around the y-axis, but is also able to damp other degrees of freedom. Due to the fact that the embodiment of Fig. 2 is similar to the embodiment of Fig. 1, like reference numerals are used for like parts.

In the embodiment according to Fig. 2, the second constraining layers 18 acting as additional leaf springs are designed as folded leaf springs. This is achieved by

removing material from the monolithic structure 11 not only in the direction of the z-axis but also in the direction of the y-axis. The second constraining layers 18 provided in the form of a folded leaf spring therefore comprise a first portion extending in the z-direction and a second portion extending in the x-direction. The first portion extending in the z-direction is characterized by the thickness $t_2$ and the length $l_2$, the portion extending in the x-direction is characterized by the thickness $t_3$ and by the length $l_3$. In the embodiment of Fig. 2 the second constraining layers 18 provided in the form of folded leaf springs do not significantly increase the stiffness of the elastic interface device 19, namely of the leaf spring to be damped in the deliberately flexible direction.

In the embodiments of Figs. 1 and 2, the elastic interface devices 10, 19 and the constrained-layer damping structures 15, 16 incorporated or integrated into said elastic interface devices 10, 19 are formed or built into a monolithic structure 11.

Fig. 3 shows a further embodiment of the present invention, namely an elastic interface device 20 designed as a leaf spring. The elastic interface device 20 is characterized by the uniform thickness $t_1$ over its entire length. The elastic interface device 20 couples or connects two structural parts 21 and 22, namely a lower structural part 21 and an upper structural part 22, in a monolithic way.

According to the present invention, at least one constrained-layer damping structure is integrated into said elastic interface device 20. According to Fig. 3, two constrained-layer damping structures 23 and 24 are fixedly attached to a flexible middle portion 25 of said elastic interface device 20, namely of said leaf spring leaving the flexible end portions 28 in the original shape. Each of said constrained-layer damping structures 23 and 24 comprises two layers, namely a first viscous or viscoelastic layer 26 and a second constraining layer 27. On both sides of the flexible middle portion 25, there is attached one of the constrained-layer damping structures 23 and 24 to said flexible middle portion 25. Within each constrained-layer damping structure 23 and 24, the first viscous or viscoelastic layers 26 are sandwiched between the second constraining layers 27 and the flexible middle portion 25. As shown in Fig. 3, the flexible middle portion 25, the viscous or viscoelastic layers 26 and the constraining layers 27 are characterized by the length $l_2$. Further on, the viscous or viscoelastic layers 26 are characterized by the thickness $t_v$, the constraining layers 27 are characterized by the thickness $t_2$. The entire thickness of the middle portion comprising the flexible middle portion 25 of the leaf spring and the two constrained-layer damping structures 23 and 24 is the thickness T shown in Fig. 3.

The constraining layers 27 are attached to the flexible middle portion 25 interposing the viscous or viscoelastic layers 26. For optimal damping, the constrained-layer damping structures 23, 24 provide a stiffness in the same order of magnitude as or at least not negligible compared to the flexible middle portion 25 of the elastic interface device 20. The constraining layers 27 have no direct contact to the structural parts 21, 22 are therefore loaded only via the viscous or viscoelastic damping layers 26. The constraining layers 27 could be made of the same or a similar material as the elastic interface device 20.

According to the present invention, constrained-layer damping structures are integrated or incorporated into the elastic interface devices themselves, namely at parts or portions where the deformation of the elastic interface devices is concentrated. For this purpose, a significant amount of passive damping is introduced, and moreover, additional over-constraints between the structural parts connected by the elastic interface device are avoided, which is highly advantageous for preserving the deterministic behavior of the elastic interface device, for example, the thermal stability in kinematic mounts and the reproducibility in elastic mechanisms, especially for viscous damping layers.

The elastic interface device may have any kind of shape, such as the leaf springs shown in Figs. 1 to 3, or as folded leaf springs, hinged leaf springs, elastic rods, elastic joints of universal or spherical construction, single or cascaded, all with or without a stiffened middle section.

The embodiments shown in Figs. 1 to 3 may be used in kinematic part fixations for high precision components, such as lenses or mirrors, electrostatic clamps and aerostatic journal bearings. Other applications where the invention may be useful are torque couplings, nests of spring fixations, self-aligning supports, for e.g. aerostatic bearing pads or the like. Alternatively, the present invention may be used in elastic mechanisms. Typical examples are elastic high-precision coordinate measuring machines, elastic manipulators, linear elastic guideways and pivots, for e.g. fast tool servo systems or wire bonders, and piezoelectric steppers.

LIST OF REFERENCE NUMERALS:

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| 10 | elastic interface device |
| 11 | monolithic structure |
| 12 | structural part |
| 13 | stiffened middle portion |
| 14 | flexible end portion |
| 15 | constrained-layer damping structure |
| 16 | constrained-layer damping structure |
| 17 | first layer |
| 18 | second layer |
| 19 | elastic interface device |
| 20 | elastic interface device |
| 21 | structural part |
| 22 | structural part |
| 23 | constrained-layer damping structure |
| 24 | constrained-layer damping structure |
| 25 | flexible middle portion |
| 26 | first layer |
| 27 | second layer |
| 28 | flexible end portion |